TRANSIENT ANALYZER FOR MAGNETIC AMPLIFIERS

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FIG. 1

FIG. 2

Determination of Transient Response of Magnetic Amplifier

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This invention relates to electronic measurement and more particularly to a simple method and apparatus for measuring the transient response of magnetic amplifiers. The transient response of magnetic amplifiers may be defined as the time required for the root-mean-square (R. M. S.) or rectified average value of output current or voltage to change a prescribed percentage of the difference between the corresponding initial and final steady state values. When the magnetic characteristics of core materials approach the rectangular B-H curve or loop shape, the wave form of the output current exhibits the typical rapid rise as one core saturates at some angle $\alpha_{MA}$ and sinusoidal form after saturation, until the end of the half cycle. Under such conditions, the peak value of the load current is independent of the average or R. M. S. value when $\alpha_{MA} < \frac{\pi}{2}$.

Conventional recording instruments are suitable for the measurement of cyclic peak values and can be adapted to measure R. M. S. or average value response time but at the expense of considerable inconvenience and difficulty. Electronic integrators can be devised for direct measurement of the rectified average values of the output taken over each cycle by portraying the response of the amplifier in terms of cyclic average values on the screen of a cathode ray oscilloscope from which the response time is determined.

An object of the present invention is to provide a method and apparatus for measuring the transient response of a magnetic amplifier that will overcome the disadvantages mentioned herebefore.

Another object is to provide a device for generating a number of pulses exactly equal to the number of cycles required for the output current or voltage of a magnetic amplifier to change from its initial value to any arbitrary or predetermined value.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a block diagram of the essential apparatus for measuring the transient response of a magnetic amplifier.

Fig. 2 is a graphical representation of the invention of Fig. 1 showing the output of the magnetic amplifier over several cycles with the reference angles superimposed thereon for a build-up transient.

Fig. 3 is a block diagram of the transient analyzer of Fig. 1 showing the pulse shapes at various junction points.

Fig. 4 is a schematic wiring diagram of a preferred embodiment of the transient amplifier of Fig. 3.

In Fig. 1, there is shown a control circuit comprising batteries $E_4$ and $E_3$ and two switches ganged together shown in clamp position, a magnetic amplifier 13, a transient analyzer 15 and an electronic counter 17 connected together. The values of the control circuit voltages $E_4$ and $E_3$ (or current) corresponding to the desired initial and final steady state values of load voltage (or current) are established. Output of magnetic amplifier 13 is then set at a reference value (i.e., 63.90 percent, etc. of the total change-duration time) by applying a suitable signal to the control circuit. Magnetic amplifier 13 saturates at some angle corresponding to the reference value of output such that:

$$\alpha_{MA} = \frac{\pi}{2}$$

where $\alpha_{MA}$ is the angle of saturation of magnetic amplifier 13 and $\alpha_R$ is designated the reference angle. If the core materials of magnetic amplifier 13 are not "ideal," the current wave will not jump abruptly at saturation, however, if $\alpha_{MA}$ is taken as the angle of maximum slope of the wave, the operation is the same as though the core materials were rectangular.

Transient analyzer 15 is designed to generate a voltage pulse of very short duration once every cycle. The phase of this reference pulse is then made to coincide with reference angle $\alpha_R$ by a manual adjustment of phase adjustment knob 19. When the output current is less than the reference value

$$\alpha_{MA} > \alpha_R$$

and, when the output current is greater than the reference value

$$\alpha_{MA} < \alpha_R$$

It is to be observed that although the above remarks apply to a single-ended magnetic amplifier, the method described can be applied to a push-pull magnetic amplifier by comparing the saturation angle of one reactor with the reference angle.

The function of transient analyzer 15 is to compare the angles $\alpha_{MA}$ and $\alpha_R$ every cycle and indicate the result by generating an output pulse every cycle for a build-up transient when $\alpha_{MA} > \alpha_R$, no pulse being generated when $\alpha_{MA} < \alpha_R$; and by generating a pulse every cycle for a decay transient if $\alpha_{MA} > \alpha_R$, no pulse being generated when $\alpha_{MA} < \alpha_R$. Analyzer 15 becomes operative only after switches 21 and 21' initiating the transient and unclamping the analyzer, respectively, are thrown to lower position. Thus, the number of pulses generated by analyzer 15 after the switches are thrown is equal to the number of cycles required for the output of the amplifier to change from the initial value to the reference value. The response time of said amplifier is obtained directly by counting the number of pulses generated by analyzer 15 during the transient. Counting can be accomplished with electronic counters of the conventional type such as multiple decade counters (having Eccles-Jordan flip-flop circuits) used in electronic digital computers. Standard recording oscillographs can also be used for counting.

The comparison of angles $\alpha_{MA}$ and $\alpha_R$ is made during one half of the cycle, the negative half (see Fig. 2). If the output of magnetic amplifier 13 is A-C, as shown in Fig. 2, the signal into analyzer 15 can be obtained from the load (i.e., load voltage). If the signal is full-wave D-C (rectified D-C) then the signal to analyzer 15 must be taken as the voltage across one reactor winding. In any event, whether full-wave A-C or D-C, the signal can always be taken from a winding of one reactor. This will be obvious from the fact that the analyzer operates by comparing the reference pulse with some negative pulse derived from the magnetic amplifier which occurs only once during a cycle.

The phase angle of reference pulse $\alpha_R$ is readily adjusted without the aid of an oscillator by setting the output of magnetic amplifier at the reference value. This
is accomplished by applying an appropriate steady state control signal to the amplifier and observing the output with a suitable A-C. or D-C. voltmeter as desired. An amplifier and phase shifter 19 are then clamped and the phase adjustment 19 varied until pulses are obtained from the output terminals. The phase adjustment is further varied until the output from amplifier 15 just ceases. Reference angle $\alpha_0$ is now adjusted (i.e., $\alpha_{MA}=\alpha_0$ for the desired, or reference, value of the output from the magnetic amplifier). Amplifier 15 is again clamped, the counter reset to zero, and the transient initiated by tripping switches 21 and 21'. At the completion of the transient, the reading of counter 17 is equal to the response time in cycles of amplifier 13.

Operation of transient amplifier 15 can best be understood by reference to Figs. 3 and 4. An input signal $A$ or $A'$ from a magnetic amplifier 13 is applied to terminals 39—39 of said amplifier. The negative half cycle of signal $A$ is removed by passing said signal through crystal diode 41 if the negative drop in the signal occurs on the positive half cycle (input from a reactor winding) and a signal which is the same frequency and in phase is removed if the negative drop occurs during the negative half cycle. The clipped signal is then amplified and differentiated by feeding the signal into amplifier and differentiator stage 23, tubes $T_{IA}$ and $T_{IB}$, resulting in a sharp negative pulse $B$ of short duration which occurs at phase angle $\alpha_{MA}$. An A-C. voltage of the same frequency whose magnitude is equal to the number of cycles required for the output current or voltage of a magnetic amplifier to change from its initial value to a predetermined value. The response time in cycles is obtained directly by recording the output of the analyzer with an electronic counter or conventional recording devices. Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. Apparatus for measuring the response time of a magnetic amplifier comprising means for accepting an output from such magnetic amplifier, means for transforming said output into a sharp negative pulse of short duration, means for comparing said pulse with a predetermined amplitude, and means for controlling the gradient angle of said magnetic amplifier until the output voltage of said magnetic amplifier is equal to the amplitude of said transformed pulse.

2. Apparatus for measuring the response time of a magnetic amplifier comprising an amplifier for accepting an output from such magnetic amplifier, a differentiating circuit connected to said amplifier for producing a sharp negative pulse of short duration coincident with the saturation angle of such magnetic amplifier, a phase-shifting circuit for accepting an adjustable phase A-C. reference voltage and for shifting the phase thereof, means for transforming said reference voltage to a sharp negative pulse of short duration and means for cyclically comparing said two pulses during the transient of such magnetic amplifier.

3. Apparatus for measuring the response time of a magnetic amplifier comprising an amplifier for accepting an output from such magnetic amplifier, a differentiating circuit connected to said amplifier for producing a sharp negative pulse of short duration coincident with the saturation angle of such magnetic amplifier, a first differentiating circuit connected to said amplifier for producing a sharp negative pulse of short duration coincident with the saturation angle of such magnetic amplifier, a phase

Pulse $K$ appears across output terminals 57 and 57'. On the other hand, during a build-up transient, if pulse $F$ occurs after pulse $E$ (i.e., $\alpha_{MA}<\alpha_s$), gate 33 will remain closed when sensing pulse $I$ arrives at the input to said gate and no pulse appears at output terminals 57—57'. For a decay transient, the rules of pulses $B$ and $F$ are interchanged by throwing reversing switch 35 to the decay position. Operation of transient analyzer 15 then proceeds as described hereinbefore.

The specific embodiment shown in Fig. 4 is designed for 60 and 400 cycles per second operation but can be easily modified for higher frequency applications. In operation, analyzer sensitivity was found to be sufficient for satisfactory operation on signals obtained from typical 10 volt, 60 C. P. S., half-wave and full-wave magnetic amplifiers employing Mumental and Hipernik V core materials. For smaller signals, an additional stage of preamplification is required.

The logic of the circuit operation requires that the input from the magnetic amplifier be sufficient to trigger flip-flop stage 32 before a pulse is emitted during the transient. Accuracy of the transient analyzer is high because of the dependence only upon the setting of the reference angle $\alpha_s$. It is seen from the apparatus and method described hereinbefore that a simple and reliable electronic device is provided for continuously comparing pulses exactly equal to the number of cycles required for the output current or voltage of a magnetic amplifier to change from its initial value to a predetermined value. The response time in cycles is obtained directly by recording the output of the analyzer with an electronic counter or conventional recording devices. Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.
5 A shifting circuit for accepting and varying the phase of an adjustable phase A-C. reference voltage, a second differentiating circuit connected to said phase-shifting circuit for producing a sharp negative pulse of short duration, a flip-flop trigger circuit connected to said first and second differentiating circuits, a gating circuit connected to said flip-flop circuit for comparing cyclically the phase of said reference and saturation pulses, whereby an output pulse is produced only each cycle for which the reference angle of said reference pulse is less than the angle of saturation of such magnetic amplifier.

4. A transient analyzer for determining the number of cycles required by a magnetic amplifier to respond to a cyclic input signal, the time of response of said amplifier being arbitrarily defined as the time required for the amplifier output to attain a predetermined condition, comprising, in combination: connections for a source of reference alternating-current signals, said reference signal being applied to said magnetic amplifier as an input signal; means for producing one pulse per cycle of the output signal from said magnetic amplifier at a time after the start of said reference signal cycle when the input signal causes said magnetic amplifier to saturate; means for shifting the phase of said reference signal; means for producing one pulse per cycle of said phase-shifted reference signal at a predeterminated time after the start of said reference signal cycle; means for producing a second pulse per cycle of said phase-shifted reference signal, said second phase-shifted pulse lagging 180 electrical degrees behind the first phase-shifted pulse; means for producing a gating signal from said magnetic-amplifier output-signal pulse and said first phase-shifted pulse; means for producing a gating signal and said second phase-shifted pulse being applied thereto, said second phase-shifted pulse being passed therethrough only when said gating means is enabled by application thereto of a gating signal which is of a type that is initiated by said magnetic-amplifier output-signal pulse and cut off by said first phase-shifted pulse; and means for determining the number of said second phase-shifted pulses passing through said gating means.

5. A transient analyzer for determining the number of cycles required by a magnetic amplifier to respond to a cyclic input signal, the time of response of said amplifier being arbitrarily defined as the time required for the amplifier output to attain a predetermined condition, comprising, in combination: connections for a source of reference alternating-current signals, said reference signal being applied to said magnetic amplifier as an input signal; means for producing one pulse per cycle of the output signal from said magnetic amplifier at a time after the start of said reference signal cycle when the input signal causes said magnetic amplifier to saturate; means for shifting the phase of said reference signal; means for producing one pulse per cycle of said phase-shifted reference signal at a time after the start of said reference signal; means for producing a second pulse per cycle of said phase-shifted reference signal, said second phase-shifted pulse lagging 180 electrical degrees behind the first phase-shifted pulse; means for producing a gating signal from said magnetic-amplifier output-signal pulse and said first phase-shifted pulse; means for producing a gating signal and said second phase-shifted pulse being applied thereto, said second phase-shifted pulse being passed therethrough only when said gating means is enabled by application thereto of a gating signal which is of a type that is initiated by said magnetic-amplifier output-signal pulse and cut off by said first phase-shifted pulse, said gating signal being of the aforesaid type only as long as said time remains longer than said time $t_M$, and means for determining the number of said second phase-shifted pulses passing through said gating means.

References Cited in the field of this patent

UNITED STATES PATENTS

2,370,692 Shepherd Mar. 6, 1945
2,517,977 Cole et al. Aug. 8, 1950
2,601,491 Baker June 24, 1952
2,666,325 Withers et al. Jan. 19, 1954
2,777,098 Duffing et al. Jan. 8, 1957

OTHER REFERENCES